Exo-Skeletal Arm Brace

First Semester Final Report

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Abstract— *Motor control loss is a societal problem that has yet to be fully assessed, even in today's technologically-based society. After a proper analysis of this societal adversary, it is seen that engineering can contribute a solution to this problem that seems unrelated at first. This report looks at motor control functionality and offers a solution in the form of an exo-skeletal arm brace. There is an organizational breakdown of the process leading to the construction of the arm brace, with task delegated to each member based on specialty offered by the design team. In this report, there will be a breakdown of each component worked on by each member up to the end of the first semester, with a project task assessment for the following semester.*

***Index Terms*—robotics, senior design, hemiparesis, cerebral, palsy, organization, brain sensor, muscle sensor, electroencephalogram, electromyography, exoskeleton**

I. Introduction

It is evident to see that technology exist because it was necessary to facilitate solutions to the needs of society, in ways that it could not have normally done in the natural world. These technological advancements have lead us to overcome various adversaries that have met society throughout history, ranging from agriculture, industrial, and medical advancements. This projects looks to add to these types of societal services that help to better the lives of people that deserve to live in a way that most people do daily.

The exo-skeletal arm brace is designed to assess a problem that most take for granted; that is that motor function in an individual can differ depending on certain ailments or their medical conditions. It is the purpose of this project to help these individuals perform everyday task that are trivial to most lifestyles in society. Included, this system will provide a non-surgical approach to conditions that could only be permanently solved through surgery otherwise.

This report will describe the system designed and the organization techniques utilized in order to accomplish the completion of said design. Each member of the design team was designated a specific feature set that cumulated in the completion of the lab prototype used for testing and proof of concept.

II. Problem Statement

Motor functions become an increasingly urgent area of concern when seen through a certain perspective. The objective is to assess this need to maintain motor functions with innovative engineering techniques that can improve rehabilitation and, ultimately, recovery for patients suffering from motor control dysfunction. Motor control loss is a common symptom resulting from a varying amount of conditions suffered by people globally such as: cerebral palsy, post-stroke hemiparesis and injury rehabilitation [2]. Research in rehabilitation continues, with more hope of full recovery becoming increasingly feasible the more researchers understand how the brain reorganizes itself.

However, if the area responsible for impairing motor function is cerebrally-based, researchers have dedicated their focus to finding ways to repair the peripheral nervous system, in order to restore the original networks the brain used to communicate with the limbs and extremities. These solutions are motivated by the idea of *internally* repairing motor functions, through various medical methods. The purpose of bringing this to light is to show one of the main motivations for designing this type of product. With these complex procedures, which are still fairly new areas of surgery, there arises a huge fatal risk factor with proceeding with such an operation. Included, the specialty needed to perform such a task leads to surgery costs that are just not feasible for most modern day citizens, with an average repair of transected peripheral nerves in the extremities totaling $1.32 to $1.93 billion dollar per year [1]. The exo-skeletal arm brace allows to a take non-surgical and less-expensive approach to a problem that can easily be resolved with technology and resources provided in this emerging technologically-based society.

III. Design Idea

When deciding on the best design proposal, it is important to factor in the design team's expertise in the matter. Considering the case for this design team, creating an exo-skeletal arm brace is the most logical design to produce when factoring in construction time and skills offered by each member. The implementation is also within the scope of the design team's experience; evading the use of any medical/surgical procedures that the team is not qualified for.

Constraints on the design differ based on the application that it's meant for. In the case of the arm brace, there are a few basic requirements that, by the end of the design process that should have been accomplished. These base-line requirements were distinguish by their innate relevance to the primary functions that are being attempted. The design requirements are as follows:

1. Replicate arm motor function at the joint of the elbow: The design has a specific joint that it is assisting. This main motor function is responsible for majority of the movements in the arm and requires consistent use. Aiding this specific joint benefits a varying range of applications, which is a major driving force that motivates this design; the more expansive the applications are, the more justifiable the societal benefit is.
2. Portability/Wearability (*planned for next semester*): The purpose of this design requirement is to be able to have a level of human-machine interfacing. That prescribes the design process to factor in the inherent result that most users will demand for; the ability to wear the exo-skeleton in a portable fashion. This requirement expands the usefulness to different environments that users will be facing, dependent on the application the user desires.
3. Light-Weight: This requirement suggests the weight of the system determines which market the design is intended for. Since the focus is predominantly concerned with individuals with medical conditions, the weight distribution and amount of weight in the system has to be determined accordingly. Considerations in weight have to encompass the lifestyles of all users, so that they have accessibility to its functions without having concerns of whether the weight will deter users from wearing it.
4. Perform specific motions: Based on the American Academy of Orthopaedic Surgeons, there is certain criteria are met for a disabled person to be considered disabled on basis of movement-range. One major criterion is that a person displays disability if the patient has flexion deformity when the forearm passes the 90 degree mark of the elbow-joint

movement range [2]. Therefore, the design will address this by making the requirement to perform certain motions that compensates for this defined lack of motion. The two motions we're addressing is the motion to open a door, and the motion to eat (bringing hand to mouth) [2].

These base-line requirements for the design are necessary for the solution to be properly addressed. It is the design team's goal to ensure these constraints are met in the most efficient way possible for the scope of the process.

IV. Work Breakdown Structure

The work breakdown structure is a technique that quantifies the task of the design process so as to make it more manageable. Based on the skill set provided by the team members involved in the design process, the separation of features set were assigned so that each one corresponded to a complementary skill owned by the member assigned to accomplish that required feature. With that in mind, the main components and the corresponding work packages are as follows:

1. **Exo-Skeleton**
- 1.1 *Robotic Arm System*
  - 1.1.1 *Frame System*
    - 1.1.1.1 Measurements
    - 1.1.1.2 Buy materials
    - 1.1.1.3 Schematic drawing
    - 1.1.1.4 Assembly
  - 1.1.2 *Cable/Pulley System*
    - 1.1.2.1 Design/Measurements
    - 1.1.2.2 Buy Materials
    - 1.1.2.3 Assembly
    - 1.1.2.4 Calibrations
  - 1.1.3 *Rotation/Joint System*
    - 1.1.3.1 Mounting Area
    - 1.1.3.2 Refabrication
- 1.2 *Communication System*
  - 1.2.1 *Hardware*
    - 1.2.1.1 Component Testing
    - 1.2.1.2 EEG/EMG Diagnostic
  - 1.2.2 *Software*
    - 1.2.2.1 Microcontroller Comm.
    - 1.2.2.2 Signal Processing
- 1.3 *Motor System*
  - 1.3.1 *Motor Driver*
    - 1.3.1.1 Calibration
  - 1.3.2 *Stepper Motor*
    - 1.3.2.1 Precision Tuning
    - 1.3.2.2 Mounting
    - 1.3.2.3 Specifications
  - 1.3.3 *Microcontroller*
    - 1.3.3.1 Flowchart
    - 1.3.3.2 Ranged Movement
    - 1.3.3.3 Mounting

The exo-skeletal arm brace consists of four major sub-systems or features: the robotic arm brace system, the motor system, the brain sensor and the muscle sensors. These major subsystems are inclusive of every aspect of the project, with each feature of the sub-systems mutually exclusive from each other.

V. Robotic Arm System

The robotic arm system is the physical display of the control used for this project. This component is crucial for a multitude of reason, but the main focus was to provide the necessary motion required of the design while being as comfortable as possible. One of the team's weaker attributes is the knowledge of mechanical design; so in order to compensate for this lack of knowledge, the team utilized the existence of other products that can satisfy some of the functionality requirements desired.

Fig.1: Original Arm Brace before fabrication

The first component that was utilized for the robotic arm brace was a pre-existing arm brace that was originally made for the purpose of post-elbow surgical operation rehabilitation, as shown in Figure 1. This product had a dial at the joint of the elbow that set limits on the range of motion desired for the user. The arm brace was refabricated by the team, replacing the angle-limitation mechanism with a 3D-printed pulley. This pulley is then connected to another 3D-printed pulley fastened onto the shaft of the motor with a custom-made coupling.

Included with the arm brace, Figure 2 shows a custom made testing mount created for the motor and the motor driver. This was made to make a concrete system that can provide the torque/speed required without the risk of moving the entire motor. Most parts were custom made in order to provide utility necessary for the design.

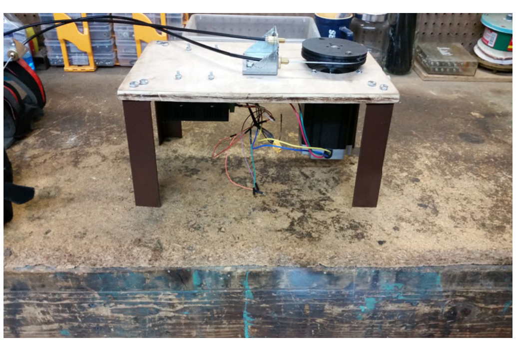


Fig.2: motor mounted on testing table

The system connecting the motor to the arm brace is a pair of wire cables wedged into fabricated slots on both the pulleys. These cables are locked under tension using the black sheath of the cable and ferules connected on the ends of the cable. Figure 3 illustrates the cable system connecting the brace to the motor. The tension can then be adjusted at will.

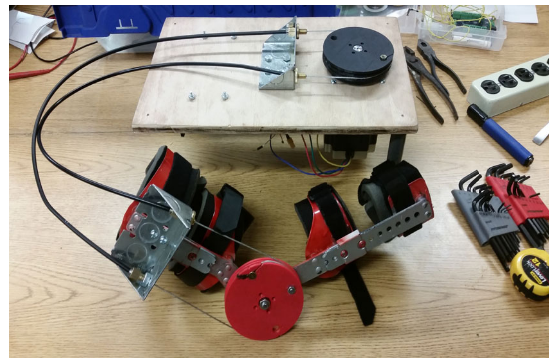


Fig.3: Arm Brace with cable system

Next semesters assignments designated for the robotic arm brace is to perfect design and prepare for a portable system. Measurements of the motor system components chosen for the final design will be taken in order to design a backpack mount. Included with that, there will be a redesign of the arm brace using alternative materials to reduce weight of the product. Currently, the material designated in the final design is the plastic filament used for the 3D printers. It is a more rational and efficient approach to making custom parts, as well I was being more light-weight, which is part of the requirements of the design.

VI. Motor System

The purpose of the motor system is to create an augmented motion at the joint of the elbow. Based on the construction of the pulley system, the translation of the movement is equivalent to the motion and speed of the motor (meaning 1:1 ratio for torque and speed). Included, the design's performance depends on the precision at which the motor can be controlled. Overall, it was necessary to have a thorough understanding of the functions of the motor system and how it contributed to the entire system as a whole. Lastly, selection of an appropriate motor had to be assessed in order to provide the most efficient system possible. If the motor chosen satisfies the design's requirements, then it will simplify the integration of the motor with the rest of the system.

The motor chosen was a NEMA 34 stepper motor made by Wantai Stepping Motors, shown in Figure 4. Stepper motors have a small degree sizes for steps, and provides a high level of torque that exceeds the requirements for the design. Included, the motor driver can alter the stepping size based on the applications, with settings up to 51200 steps per rotation. This degree of precision is desirable for the products application.

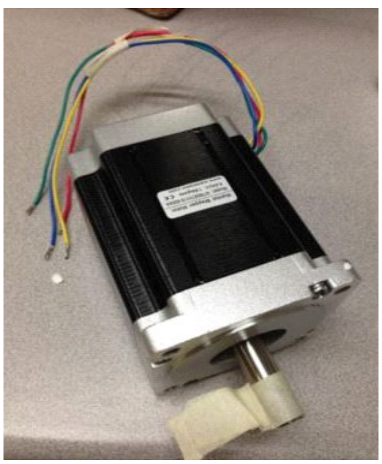


Fig.4: NEMA 34 motor

Figure 5 shows a flowchart that was assembled based on the functions contributing to the motor. The reason the motor system required a flowchart was because it was the object containing the control variable of the entire system. If a proper control algorithm can be established for the motor, the system itself would be prescribed the algorithm as well. The flowchart showed how the microcontroller controls the stepper motor based on the signals received by the muscle/brain sensors; it also restricted the range of motion at which the motor can be rotated. Using the flowchart, the motor was interfaced with the muscle and brain sensors with the microcontroller, verifying that everything functioned as expected.

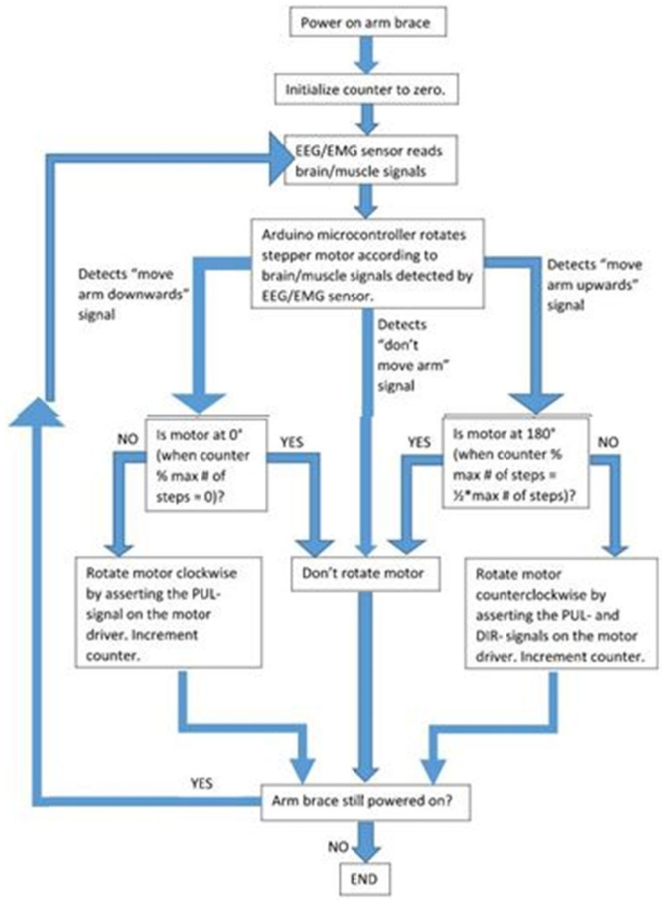


Fig.5: Flowchart for exo-skeletal arm brace

For next semester, the goal for the motor system is to reduce the weight of system by replacing some of its parts with their lightweight counterparts. The parts in particular are the stepper motor, motor driver, and power source. The stepper motor in current use weighs 15 pounds and this much weight could be a burden for some user. The motor will be replaced by the NEMA 23 bipolar stepper motor which weighs only 1.2 kg (2.65 lbs).

The motor driver in use currently takes up too much space, so there will need to be a smaller motor driver which is compatible with the NEMA 23 stepper motor. The Wantai DQ420MA motor driver would work with the new motor planned to be used; it supports an input voltage between 12-36 V and the NEMA 23 motor supports a voltage between 24-48 V.

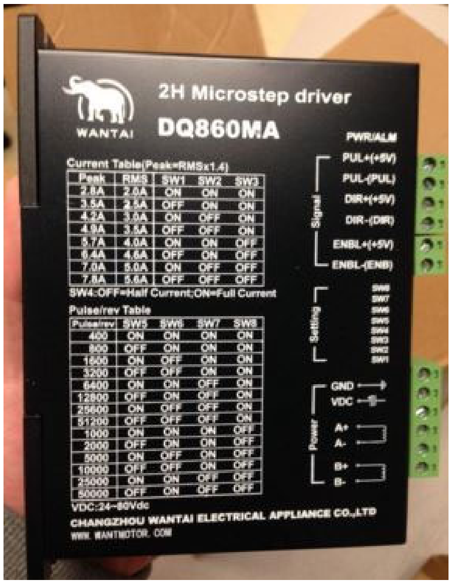


Fig.6: motor driver in use for lab prototype

The power source that is currently used to power the arm brace requires being plugged into a wall outlet, so it needs to be replaced with a portable rechargeable battery pack for next semester. The battery pack should provide a current of at least 2.8 A (which is the rated current of the NEMA 23 stepper motor found while researching new parts to use next semester) but no more than 5.6 A (which is twice the rated current). Since the new stepper motor can support voltages between 24-48 V, the power supply must have a voltage within that range.

VII. MUSCLE SENSOR (ELECTROMYOGRAPHY)

The muscle sensors are used to determine the speed at which the motor rotates, which in turn accounts for how fast the arm brace rotates. The input expressed by the contraction of the bicep is analogous to the delay time between steps in the motor. Figure 7 shows the placement and circuit schematic connecting the EMG to the microcontroller. When the bicep is contracted, it displays a larger voltage difference, meaning to speed the rotation of the motor (less delay between steps). The speed is controlled proportionally, with a gain value varying depending on the sensitivity desired by user.

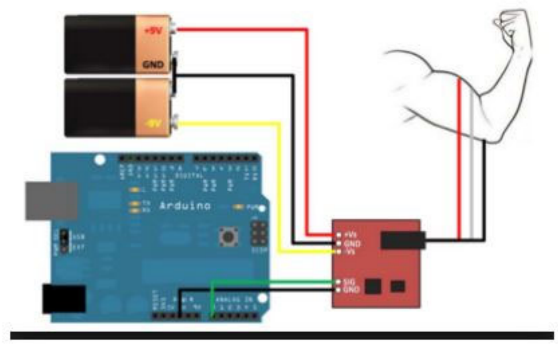


Fig.7: EMG sensor placement/schematic [4]

For the lab prototype, the team tested the control ability of this sensor (also referred to as electromyography, EMG) by recording its voltage output while it was integrated with the motor system, illustrated by Figure 8. The basic principle of the control theory is that the analog input of the EMG (in the form of voltage) goes into the microcontroller, and based on the value of that voltage the delay between steps is decreased. Larger values in the EMG output a smaller delay in the stepping size. Below is an experiment conducted by one of the team members in which he performed a series of motions and record the voltage output of the EMG.

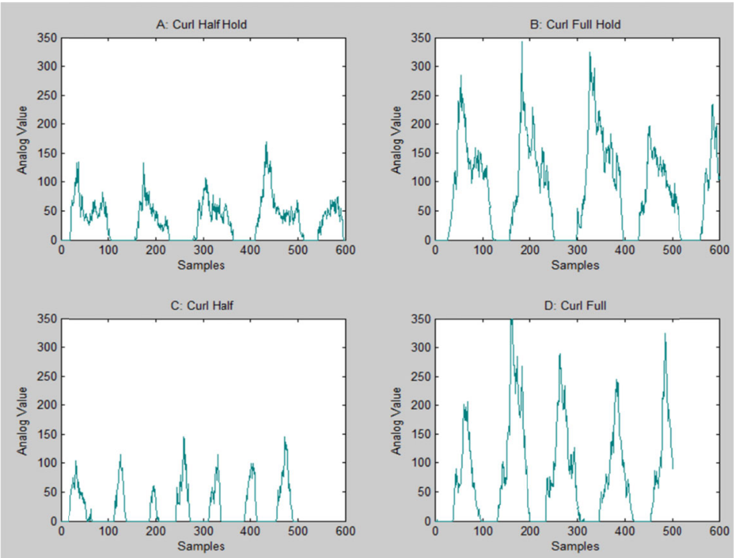


Fig.8: Data collection of EMG readings

As he lets down his arm, the value is decreasing. We were able to use consistent values similar to these readings and integrate into how fast desired for the motor rotation. This works by passing these analog values into the delay function of the microcontroller, which in our case is the control factor of how fast the motor rotates.

For next semester, the design team would like to make the EMG sensors much more fashionable and more comfortable to wear, as the design idea is to make it wearable. Conductive fabrics will be used to replace the electrode pads of the EMG. Then it will be fabricated to the conductive materials onto an arm sleeve. Included, the algorithm at which the sensors obey needs to be improved. Included, there will be implementation of more advance algorithm in learning the readings received from the EEG or/and EMG sensors.

VIII. Brain Sensor (Electroencephalogram)

The brain sensor is a complex, but crucial component of the exo-skeletal arm brace. If we were to refer back to the original problem statement at hand, some of these conditions are caused by a physical damage or malfunction of the nervous system. For patients with more severe conditions, muscle sensation will simply not suffice as the only means of control.

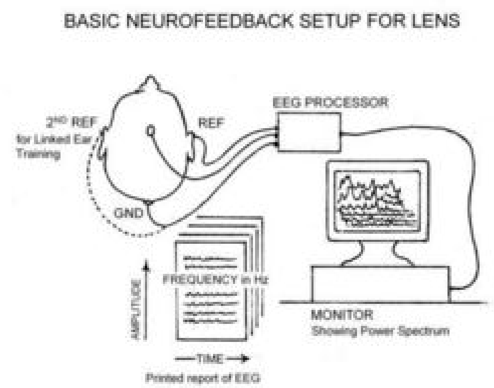


Fig.9: Basic theory of brain sensor readings

The brain sensor is utilized so that there is an additional component used to control a different aspect of the rotation. The EMG sensor is used to control the speed, where as the brain sensor (referred to as an electroencephalogram, EEG) is used to control the *direction* of rotation. This is beneficial because this brain sensor works as a bypass between the brain and the joint desired for control, where there could exist nerve damage that would prohibit consistent readings.

Overall the prototype performs well to the EEG and is responsive to desired commands. The basic distinction desired are signals that represent extending the arm as well as curling the arm. This basically translates to a binary-type command; whether the direction bit for the motor is clockwise or counterclockwise.

Counterclockwise corresponds with curling the arm into the body. The signal chosen to represent the direction of the motor is going to be the alpha and beta waves produced by the brain. Alpha waves occur at around 8-15 Hz; corresponding to when an individual is in a “relaxed” state of mind. Beta waves are around 15-30 Hz which occur when an individual is focused;

concentrating or in an alert state of mind. Included, the prototype required the EEG sensor to be connected via Bluetooth. The sensor was connected to the microcontroller using an hc-05 Bluetooth module (Figure 10) connecting the existing Bluetooth capabilities in the Neurosky headset. Figure 11 shows the physical nature of the headset.

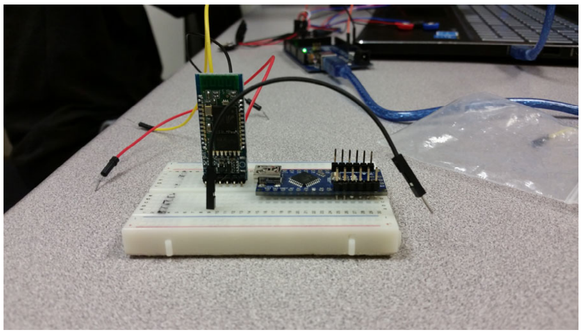


Fig.10: hc-05 Bluetooth module circuit

In order to test the signals produced, there was a set of error checks utilized in the microcontroller program. In this testing experiment, the sensor was required to meet various conditions to prove operation of the sensor, therefore ensuring the signals are one's produced by the user. Some of the conditions measured were electrode connectivity and different baseline signals produced by the brain.

Fig.11: Neurosky EEG headset

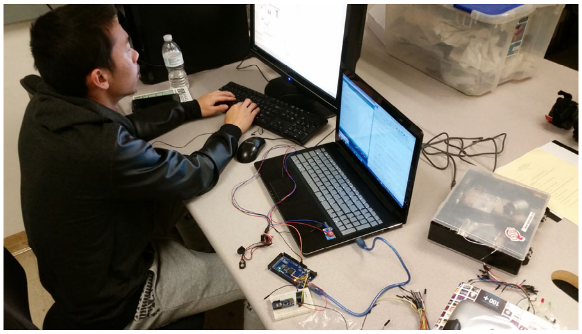
To produce the direction signals desired, the user was entirely responsible for the production of the correct signals. In order to make the process as simplistic for the user to utilize, there was a clear description between clockwise/counterclockwise. The focus of the individual was measured on a scale from 0-100 units, where 0-49 corresponded to extension and 50-100 corresponded to curling the arm.

One of the biggest issues faced in regards to the EEG sensor has been being able to get consistent readings and keep those readings held for a specific period of time. The EEG is able to record even the smallest electrical activity going on in the brain. This is why next semester the goal for this component of the design will be to spend time designing a way to reduce, and overall filter out some of these signals that are introduced as noise in the system. Included, there will also be a portion of the next course debugging the code for the sensors utilized, in order to reduce the amount of delays and increase the responsiveness of the control system.

IX. Conclusion

The progress of the project up to this point has been positive in most aspects. At the beginning of the course, the design team had a rough time initially, but since then the project timeline and accomplishments have been consistent and on schedule. The goal of the design team is to continue in this trend of work ethic, hoping to create the most optimal product possible for the design.

The next semester will finalize all the expectations for the exo-skeletal arm brace. The main focus of the team is perfecting the design in all aspects, ranging from sensors, software and programming algorithms. The main requirements the team assessed in the first half of the senior design process and providing a lab prototype that assessed the main problem at hand, motor control loss. In that, the design team created a prototype the compensated for that motor control loss. The final steps are making this solution portable in fashion; creating light-weight materials and components that will suffice this need. Along with that, using more appropriate components for this type of design will be assessed as well.



It is the hope of the team that this product truly contributes to society in a positive form. With technologies such as the one designed by this senior design team, it is seen that engineering has so much to offer to society that is eventual that there will be technological solutions to *all* medical conditions. In this instance, the team's ultimate goal was to advance an ever-growing society in that very fashion.

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